Further search for T-violation in the decay $K^+ \to \pi^0 \mu^+ \nu$

M. Abe[a], M. Aliev[b], V. Anisimovsky[b], M. Aoki[c], Y. Asano[a], T. Baker[d], M. Blecher[e], P. Depommier[f], M. Hasinoff[g], K. Horie[h], Y. Igarashi[h], J. Imazato[h], A. Ivashkin[b], M. Khabibullin[b], A. Khotjantsev[b], Yu. Kudenko[b], Y. Kuno[c], K.S. Lee[i], A. Levchenko[b], G.Y. Lim[h], J. Macdonald[j], O. Mineev[b], N. Okorokova[b], C. Rangacharyulu [d], S. Shimizu[c], Y.-M. Shin[d], N. Yershov[b], and T. Yokoi[h]

(*Presented by Yu. Kudenko for the KEK E246 Collaboration*)

[a]University of Tsukuba, 305-0006, Japan
[b]Institute for Nuclear Research RAS, 117312 Moscow, Russia
[c]Osaka University, 560-0043, Japan
[d]University of Saskatchewan, S7N 0W0, Canada
[e]Virginia Polytechnic Institute & State University, USA
[f]University of Montreal, H3C 3J7, Canada
[g]University of British Columbia, Vancouver V6T 1Z1, Canada
[h]KEK, 305-0801, Japan
[i]Korea University, Seoul 136-701, Korea
[j]TRIUMF, V6T 2A3, Canada

Abstract

A new result for the transverse μ^+ polarization, P_T, in the decay $K^+ \to \pi^0 \mu^+ \nu$ has been obtained in the KEK E246 experiment. Combined with our earlier result, $P_T = (-1.12 \pm 2.17(stat) \pm 0.90(syst)) \times 10^{-3}$ and $\mathrm{Im}(\xi) = (-0.28 \pm 0.69(stat) \pm 0.30(syst)) \times 10^{-2}$, which are consistent with no T-violation.

1 Introduction

The transverse muon polarization, P_T, in the decay $K^+ \to \pi^0\mu^+\nu$ ($K_{\mu 3}$) provides a good opportunity to search for CP-violation beyond the Standard Model (SM), and it can provide insight into the origin of CP-violation. This polarization vanishes in the SM [1], but it can be as large as $10^{-2} - 10^{-3}$ in models with multi-Higgs doublets, leptoquarks, left–right symmetry or SUSY [2]. Since the contribution to P_T from final state interactions was found to be $< 10^{-5}$ [3], a larger value of P_T would be a clear indication of physics beyond the SM by inferring a non-zero $\mathrm{Im}(\xi)$, where $\xi(q^2) = f_-(q^2)/f_+(q^2)$ is the ratio of two form factors, $f_\pm(q^2)$ in the $K_{\mu 3}$ decay matrix element [4]. The previous result, $P_T = (-4.2 \pm 4.9(stat) \pm 0.9(syst)) \times 10^{-3}$ and $\mathrm{Im}(\xi) = (-1.3 \pm 1.6(stat) \pm 0.3(syst)) \times 10^{-2}$ was obtained in [5] for the 1996-97 data set. In this paper we present a new result of one of the analyses of the data collected in 1998-2000 combined with our previous published result.

2 Experiment

The E246 experiment was carried out at the KEK 12-GeV proton synchrotron. Detector elements are described in Ref. [6]. In this experiment, the $K_{\mu 3}$ decay of a stopped K^+ is identified by detecting the π^0 as well as the μ^+ from the decay. The E246 setup is shown in Fig. 1. A 660-MeV/c kaon beam is slowed down in a degrader and stopped in a scintillating

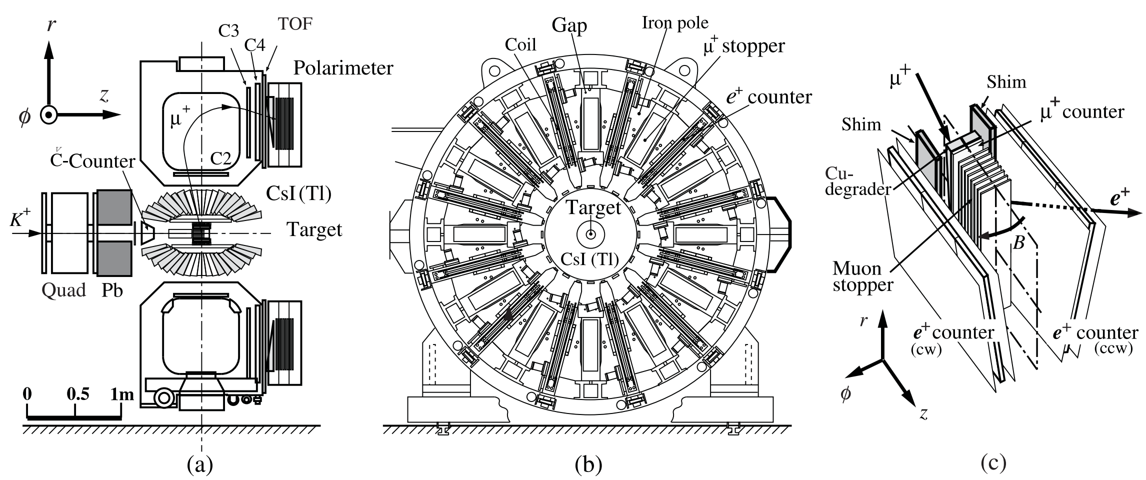

Figure 1: Setup; (a) side view, (b) front view, and (c) one sector of the polarimeter.

fiber target. The energy and direction of the π^0 from the $K_{\mu 3}$ decay are measured by a segmented CsI(Tl) photon detector installed in the central region of a superconducting toroidal magnet. A muon from the $K_{\mu 3}$ decay at rest is momentum–analyzed in magnet gaps by tracking in the stopping target, a scintillating ring hodoscope surrounding the target, and three MWPCs (C2, C3, C4). The muon exiting the spectrometer is stopped in a polarimeter in which the decay positron asymmetry A_T is measured in order to

obtain P_T. The polarimeter consists of 12 azimuthally arranged Al stoppers, aligned with the magnet gaps, with scintillator counter system located between the magnet gaps. A positron from the decay of $\mu^+ \to e^+\nu\bar{\nu}$ is detected by plastic scintillator counters located between the stoppers.

In the new analysis, the $K_{\mu 3}$ event selection is similar to [5]. The μ^+ momentum region of 100–190 MeV/c was used to remove the $K_{\pi 2}$ decays. Most of the muons from pion decay in flight in $K_{\pi 2}$ are rejected by using the χ^2 cut in tracking. Neutral pions from the $K_{\mu 3}$ decay are identified either by $\gamma - \gamma$ coincidence in the CsI and applying a cut on the pion invariant mass (2γ events), or by one detected photon with large E_γ (1γ events). The K_{e3} events which also satisfy these requirements are removed by time-of-flight. In-flight kaon decays were suppressed by a requiring a delayed decay after a K^+ is stopped. The "good" $K_{\mu 3}$ events were separated into two classes: fwd events with the angle between $\pi^0(\gamma)$ and beam direction $\theta_{\pi^0,\gamma} < 70°$ and *bwd* events with $\theta_{\pi^0,\gamma} > 110°$.

The signal was extracted by integrating the positron time spectrum from $\mu^+ \to e^+\nu\bar{\nu}$ decays of muons stopped in the polarimeter after subtraction of the background. The T-violating asymmetry A_T is obtained as a difference in the counting rate between clockwise (cw) and counter-clockwise (ccw) emitted positrons. Summing of the cw (N_{cw}) and ccw (N_{ccw}) positron counts over all 12 sectors, A_T is derived from

$$A_T = \frac{1}{4}\Big[\frac{(N_{cw}/N_{ccw})_{fwd}}{(N_{cw}/N_{ccw})_{bwd}} - 1\Big]. \tag{1}$$

Then, $P_T = A_T/(\alpha \cdot f)$, where the analyzing power of the polarimeter is $\alpha = 0.281 \pm 0.015$, obtained from asymmetry measurement of the in-plane component of μ^+ polarization, P_N, by selecting π^0s emitted transverse to the beam and comparing to a Monte Carlo calculation. The kinematic attenuation factor f results from accepting fwd and *bwd* events with $|\cos\theta_{\pi^0,\gamma}| > 0.342$ and was also obtained from a Monte Carlo calculation. It has different values for 1γ and 2γ events: $f = 0.72 - 0.77$ for 2γ and $f = 0.56 - 0.66$ for 1γ events, depending on the background level in the CsI. Then, $\mathrm{Im}(\xi) = P_T/\Phi$, where $\Phi \simeq 0.33(0.29)$ for 2γ (1γ) events is a kinematic factor obtained from the analysis of the $K_{\mu 3}$ Dalitz distribution.

The contamination of the beam accidental backgrounds in "good" $K_{\mu 3}$ events was about 8% (2γ), $\sim$ 9% (1γ), and the constant background in the polarimeter was $11-12\%$. These backgrounds only diluted the sensitivity to P_T by 10%, but they did not produce any spurious T-violating asymmetry. The main systematics uncertainties in P_T come from the two large in-plane components of the μ^+ polarization, P_L which is parallel to the muon momentum and P_N ($P_T \ll P_{N,L} \leq 1$). The largest systematic errors are due to the misalignment of the polarimeter, the asymmetry of magnetic field distribution, and the asymmetrical kaon stopping distribution. Most of these effects are canceled by the azimuthal symmetry of the detector as well as by the fwd/bwd ratio. For example, the effect of the kaon stopping distribution is reduced by more than a factor of 10 [**?**]. The total systematic error of P_T is estimated to be the same as that of the previous result [5].

The data analysis was performed by two independent groups. Both analyses obtained consistent results for 1996-97 data set (see Ref. [5]). The result for 1998-2000 data set

was obtained by one of the analyses.

3 Result

In 1998–2000 we selected about 4.4×10^6 "good" $K_{\mu 3}$ events. To check the stability of the result, all data–taking periods, including 1996-97, were divided roughly in 100-hour time intervals, and A_T for 1γ and 2γ events in each interval were calculated. The results are presented in Fig. 2. The average asymmetries for both classes of events are consistent

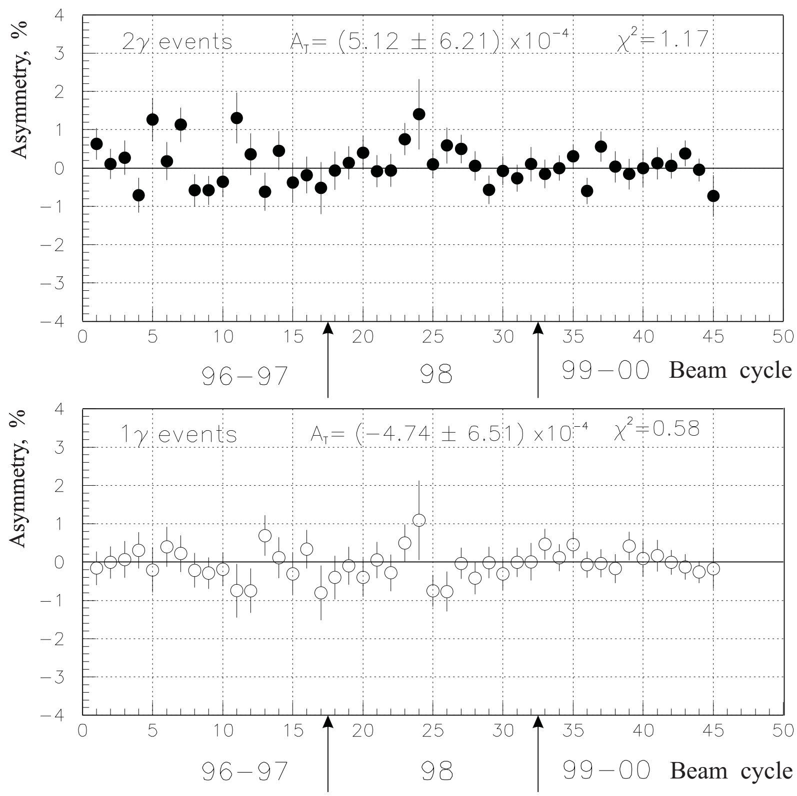

Figure 2: T-violating asymmetry consistency check for 2γ and 1γ $K_{\mu 3}$ events. Independent statistical errors are shown. Vertical arrows separate three long beam cycles. For 1996-97 cycle the results of one of the analyses are plotted.

with zero within a $\pm 1\sigma$ interval.

Combining the new and previous results[1], we obtain preliminary $P_T = (-1.12 \pm 2.17(stat) \pm 0.90(syst)) \times 10^{-3}$ and $\mathrm{Im}(\xi) = (-0.28 \pm 0.69(stat) \pm 0.30(syst)) \times 10^{-2}$, consistent with no T-violation in $K_{\mu 3}$.

[1]For the previous result the newly obtained value of α was also applied

References

[1] I. I. Bigi and A. I. Sanda, CP violation, Cambridge Monogr. Part. Phys. Nucl. Phys. Cosmol. **9**, 1 (2000); E. Golowich and G. Valencia, Phys. Rev. D **40**, 112 (1989).

[2] G. Belanger and C. Q. Geng, Phys. Rev. D **44**, 2789 (1991); C. Q. Geng and S. K. Lee, Phys. Rev. D **51**, 99 (1995) [arXiv:hep-ph/9410347]; M. Kobayashi, T. T. Lin and Y. Okada, Prog. Theor. Phys. **95**, 361 (1996) [arXiv:hep-ph/9507225]; G. H. Wu and J. N. Ng, Phys. Rev. D **55**, 2806 (1997) [arXiv:hep-ph/9610533]; M. Fabbrichesi and F. Vissani, Phys. Rev. D **55**, 5334 (1997) [arXiv:hep-ph/9611237].

[3] A. R. Zhitnitsky, Sov. J. Nucl. Phys. **31**, 529 (1980) [Yad. Fiz. **31**, 1024 (1980)]; V. P. Efrosinin *et al.*, Phys. Lett. B **493**, 293 (2000) [arXiv:hep-ph/0008199].

[4] N. Cabibbo and A. Maksymowicz, Phys. Lett. **9** (1964) 352; **11** (1964) 360(E); **14** (1965) 72(E).

[5] M. Abe *et al.* [KEK-E246 Collaboration], Phys. Rev. Lett. **83**, 4253 (1999); M. Abe *et al.* [KEK-E246 Collaboration], Nucl. Phys. A **663**, 919 (2000).

[6] A. P. Ivashkin *et al.*, Nucl. Instrum. Meth. A **394**, 321 (1997); D. V. Dementyev *et al.*, Nucl. Instrum. Meth. A **440**, 151 (2000); M. M. Khabibullin *et al.*, Instrum. Exp. Tech. **43**, 589 (2000) [Prib. Tekh. Eksp. **N5**, 9 (2000)].

[7] Y. G. Kudenko, Nucl. Instrum. Meth. A **494**, 318 (2002) [arXiv:physics/0205045].